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AN ELECTRONIC SPECKLE PATTERN INTERFEROMETRY SYSTEM FOR THE STUDY OF MISTUNED BLADED DISKS

Attention: Brian P. Sanders, Major, USAF
Program Manager, Structural Mechanics
Air Force Office of Scientific Research
Tel: (202) 767-6963

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Institution: The University of Michigan
Division of Research Development and Administration
3003 South State
Ann Arbor, Michigan 48109-1274

Project Representative: Neil D. Gerl
Division of Research Development and Administration
Tel: (734) 763-6438

Principal Investigator: Christophe Pierre
Professor
Department of Mechanical Engineering and Applied Mechanics
3112 G. G. Brown
The University of Michigan
Ann Arbor, Michigan 48109-2125
Tel: (734) 936-0401

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A state-of-the-art facility has been developed for the experimental study of the vibratory response of bladed-disk assemblies. An Electronic Speckle Pattern Interferometry system provides real-time, full-field imaging of the vibration of a test specimen, while a Single Point Laser Vibrometer, mounted on a two-stage linear positioning assembly, provides high accuracy quantitative vibration measurements at any location on the surface of the specimen. Vibration of the test speciment is driven by a novel acoustic excitation system, which delivers a traveling-wave forcing to the blink specimen that replicates the excitation to which industrial bladed disks are subject. A 24-blade experimental blink (integral bladed disk) has been designed and manufactured to precision tolerances specifically for use in this experimental facility. The blink is nearly perfectly tuned but can be systematically mistuned in a controlled fashion in order to study mistuning phenomena.
The setup has been shown to be extremely effective at rapidly identifying and accurately quantifying the complex vibration characteristics of blinks. The measurement capabilities provided with this unique facility will allow the dynamic behaviors of both tuned and mistuned configurations to be thoroughly documented and compared with predictions based on existing and developing theories of mistuning phenomena. This facility will also be used to develop a method for identifying the mistuning characteristics of industrial blinks.

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Christophe Pierre
Professor

Department of Mechanical Engineering and Applied Mechanics
3112 G. G. Brown
The University of Michigan
Ann Arbor, Michigan 48109-2125
Tel: (734) 936-0401

ABSTRACT

A state-of-the-art facility has been developed for the experimental study of the vibratory response of bladed-disk assemblies. An Electronic Speckle Pattern Interferometry system provides real-time, full-field imaging of the vibration of a test specimen, while a Single Point Laser Vibrometer, mounted on a two-stage linear positioning assembly, provides high accuracy quantitative vibration measurements at any location on the surface of the specimen. Vibration of the test specimen is driven by a novel acoustic excitation system, which delivers a traveling-wave forcing to the blisk specimen that replicates the excitation to which industrial bladed disks are subject. A 24-blade experimental blisk (integral bladed disk) has been designed and manufactured to precision tolerances specifically for use in this experimental facility. The blisk is nearly perfectly tuned but can be systematically mistuned in a controlled fashion in order to study mistuning phenomena.

The setup has been shown to be extremely effective at rapidly identifying and accurately quantifying the complex vibration characteristics of blisks. The measurement capabilities provided with this unique facility will allow the dynamic behaviors of both tuned and mistuned configurations to be thoroughly documented and compared with predictions based on existing and developing theories of mistuning phenomena. This facility will also be used to develop a method for identifying the mistuning characteristics of industrial blisks.

1 Equipment Purchased

The following equipment was purchased:

1. Electronic Speckle Pattern Interferometry (EPSI) System from Karl Stetson Associates, $76,725.00. This amount includes both the ESPI system and the laser source described in the grant proposal.

2. Single Point Laser Vibrometer (SPLV) from Polytec PI Inc., $27,053.97, as described in the original grant proposal.

3. Vibration Isolation Table (RS4000) from Newport Corporation, $9,537.05, as described in the original grant proposal.

4. Two Stage Linear Positioning Assembly from Aerotech, $17,413.00. This equipment, not listed in the original proposal, was deemed necessary in order to accurately position the SPLV system.

The following equipment, listed in the original grant proposal, was not purchased:

1. Excitation Generators (4 x Stanford Research Systems DG535 and Output Amplifiers).

In place of this system, excitation is being provided by six existing Hewlett-Packard 8904A Signal Generators, which drive small acoustic sources (speakers) behind each blade of the test specimen.

2 Experimental Setup

The integration of the equipment purchased provides a powerful system for the study of the vibratory response of bladed-disk assemblies. The Electronic Speckle Pattern Interferometry (ESPI) system provides real-time full-field imaging of the displacement pattern ("fringes") of a test specimen, allowing instant identification of localized or extended vibration mode shapes. The excitation of the test blisk can be synchronized with the bias-mirror of the EPSI system to allow fast post-processing of the acquired images, from which quantitative data can be extracted. In conjunction with this, the Single Point Laser Vibrometer (SPLV) provides high accuracy quantitative vibration measurements at any location on the surface of the test specimen. The SPLV is moved accurately into position by the two stage Linear Positioning Assembly, and this system can be programmed to take data from an array of points. Both the ESPI and SPLV systems are mounted on the Vibration Isolation Table, along with the fixture holding the test specimen and excitation sources. Figure 1 shows the experimental setup, including a test specimen and the EPSI and SPLV systems on the

Isolation Table, as well as the computer and accompanying hardware which control these systems. Figure 2 is a direct view of the EPSI system, on the table, and the SPLV system, mounted on the Linear Positioning Assembly.

Excitation is provided acoustically by small speakers mounted behind each blade. The phase-synchronized Signal Generators which drive the speakers provide up to 24 signals with a prescribed phase difference. This creates a traveling wave excitation pattern which mimics the effect of rotating the test specimen at high speed. Figure 3 shows an example of this acoustic excitation system in place behind a 22-bladed disk provided by Wright-Patterson Air Force Base.

3 Research Description

Preliminary tests on the 22-bladed disk shown in Figure 3 have demonstrated the effectiveness of the experimental setup in rapidly identifying and accurately quantifying the vibration characteristics of blisks. The acoustic excitation system has also been developed and tested using this blisk, and the control of the excitation has been integrated with the control of the optical measurement systems.

A 24-bladed disk with simple geometry has been designed for experimental studies of mistuning phenomena. Figure 4 shows the design, which features blades of rectangular cross section and dimensions chosen to minimize the effects of manufacturing tolerances. The blisk is currently being machined to extremely precise tolerances in order to provide a "tuned" baseline. After the behavior of the tuned case is analyzed using the experimental equipment, controlled amounts of mistuning will be added to the blisk. The measurement capabilities provided by the ESPI and SPLV systems will allow the dynamic behavior of both tuned and mistuned cases to be thoroughly documented and compared with predictions based on existing and developing theories of mistuning phenomena.

The optical measurement systems will also be used to develop a method for identifying the mistuning characteristics of industrial blisks. The full-field images available with the ESPI system will allow rapid characterisation of vibration mode shapes of test specimens, and the precision data acquired by the SPLV will then be analyzed to extract the amount of mistuning present in individual blades. This method will be developed using the experimental blisk discussed above, and then tested on a variety of industrial blisks.

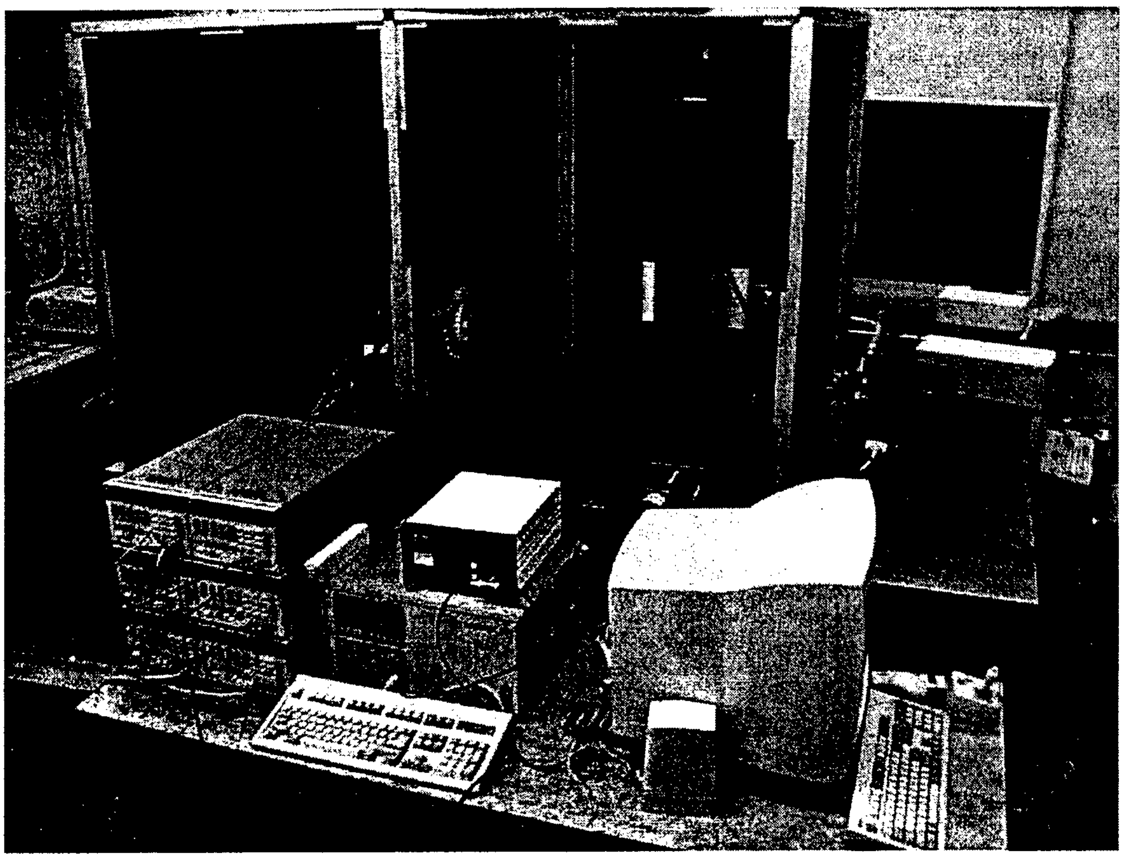

Figure 1: Experimental setup including test specimen, excitation system, control hardware, and optical measurement systems (EPSI and SPLV)

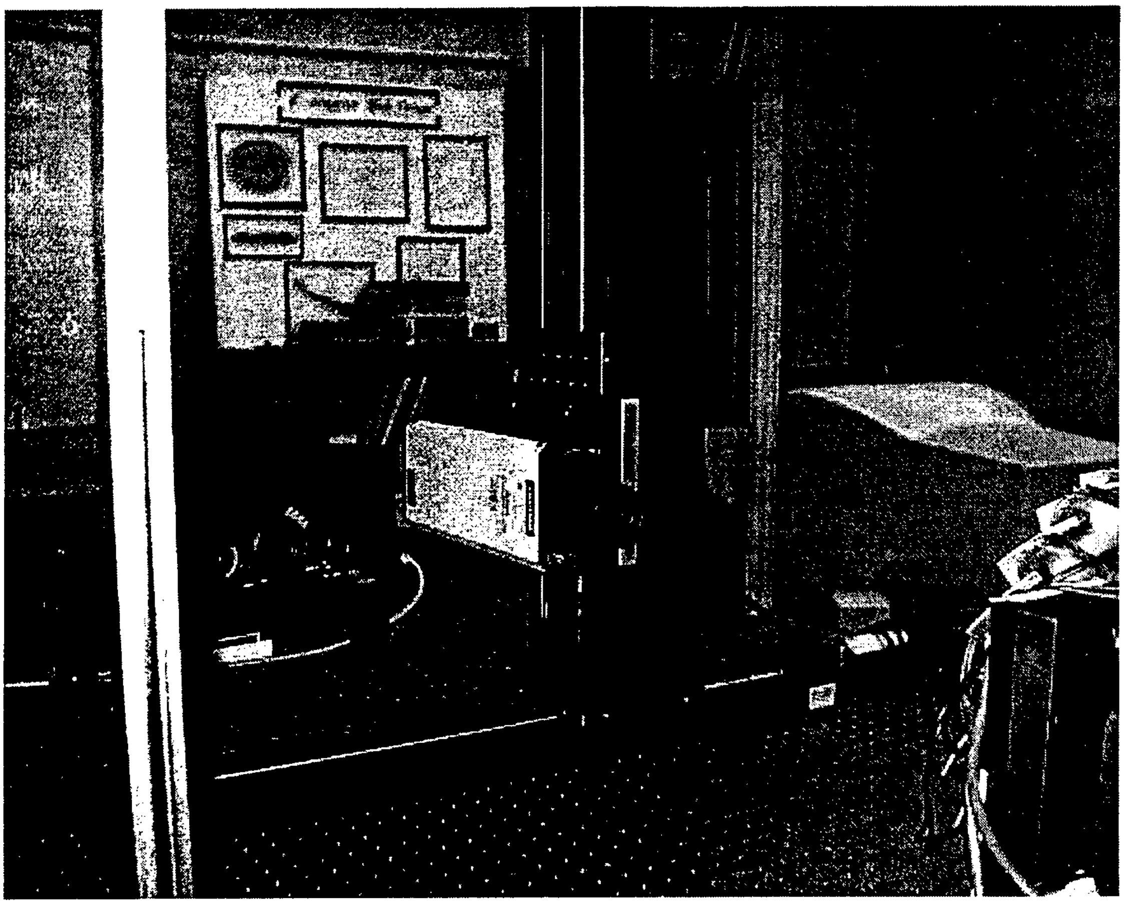

Figure 2: Electronic Speckle Pattern Interferometry System and Single Point Laser Vibrometer mounted on two stage Linear Positioning Assembly

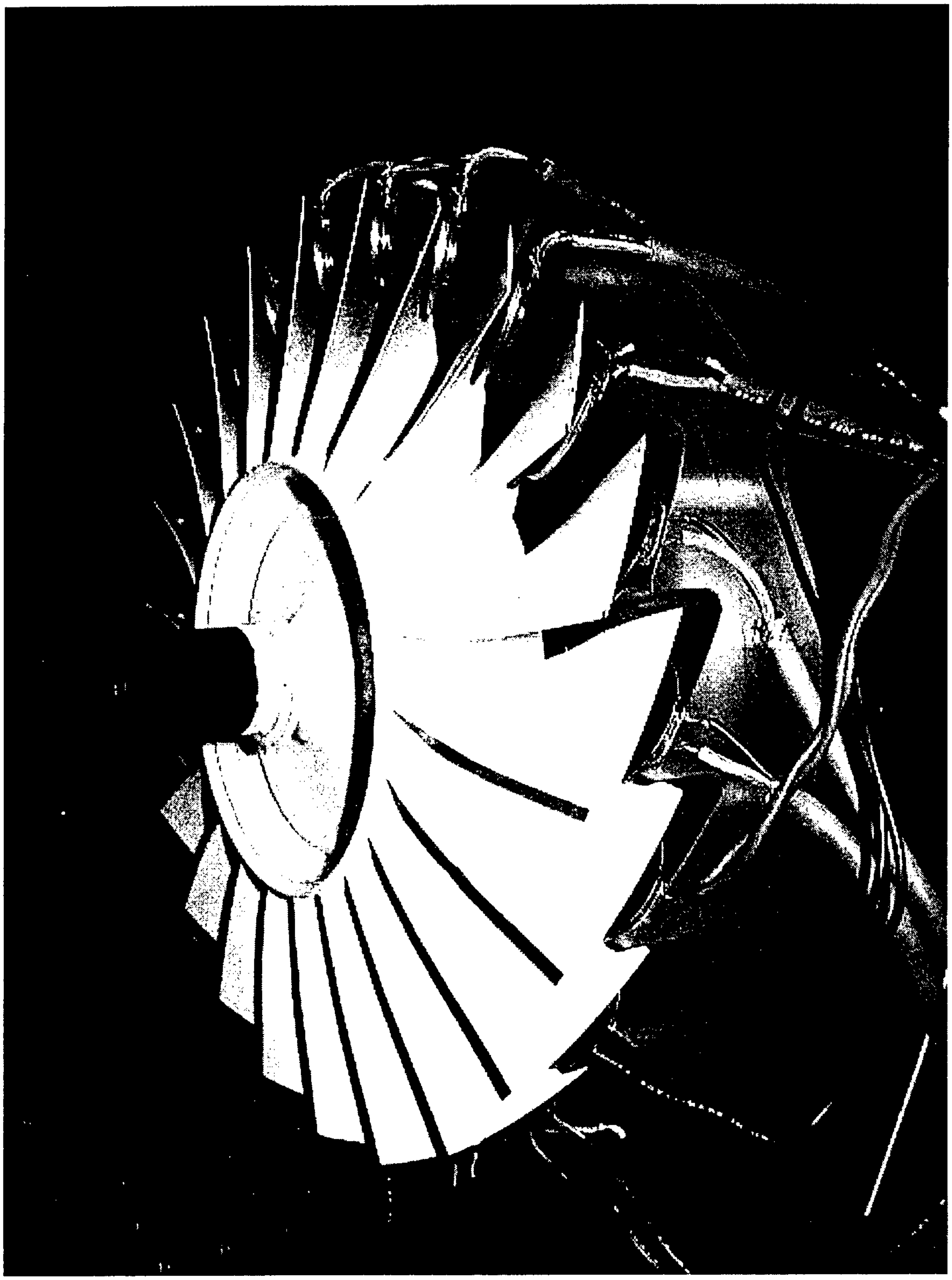

Figure 3: Speakers providing excitation to a 22-bladed test specimen

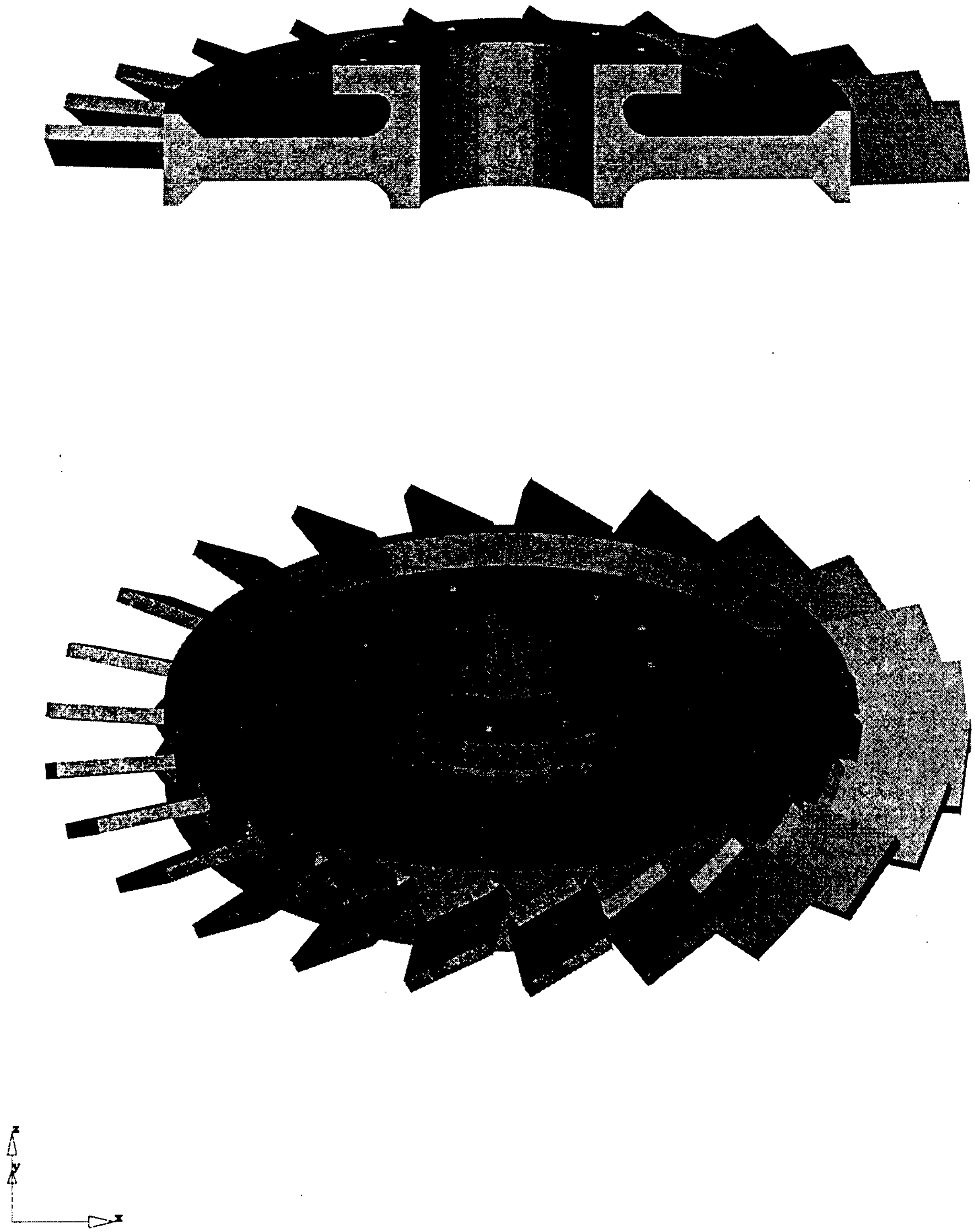

Figure 4: Images of experimental blisk design (top image is cut-away to show cross section)